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# TESTING METHODS FOR ASPHALT-RUBBER

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Final Report - Phase I

# TESTING METHODS FOR ASPHALT-RUBBER

by

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16. Abstract

The study is concerned with laboratory testing of an asphalt and rubber (A-R) mixture with special emphasis towards its use to minimize reflection cracking. Tests on the A-R blend showed that it had higher viscosity at high temperature and lower viscosity at low temperature than did the base 120 pen asphalt. Ductility values at 25, 12.7 and 0.5°C ranged from 16 to 29, thus showing good low temperature ductility. Two special tests were developed to compare A-R and RC-250 as tack coats and acting as strain attenuating layers (SAL). A-R was shown to be effective as a SAL in the "horizontal shear test," a static load test. The other new test, a repeated beam deflection test (vertical shear test) was capable of separating the test-response of the A-R and RC tack coats but not for the various application rates of A-R.

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Final Report - Phase I

TESTING METHODS FOR ASPHALT-RUBBER


## Abstract

This report is concerned with laboratory testing of an asphalt and rubber mixture. The blend is called asphalt-rubber since the amount of rubber used and the characteristics of the blend are quite different than those reported in the asphalt paving literature. Tests performed on a blend of asphalt-rubber were (a) ductility with variable elongation rate and temperature, and (b) absolute viscosity with variable temperature.

The major portion of the study was devoted to developing equipment and test procedures for evaluating the use of asphalt-rubber as a strain attenuating layer to minimize reflection cracking in asphaltic concrete. Two test procedures were used to obtain the response of the asphalt-rubber layer when subjected to an increasing axial shearing force and also to a repeated transverse shearing force. Variables in the axial shear test were thickness of asphalt-rubber layer, thickness of overlay, and extension rate; while the variables for the transverse shear were thickness of asphalt-rubber layer, thickness of overlay, amount of the repeated transverse force (by deflection) and temperature.

The results of the testing program are used to discuss the possible reasons for the successful use of asphalt-rubber as a strain attenuating layer in asphalt overlay or new construction.

## INTRODUCTION

Arizona, as well as many other states, has experienced the frustration of overlaying a cracked pavement with asphaltic concrete which subsequently shows the effects of reflection cracking. A reflection crack is one that develops in an overlay and which is directly over a preexistent crack in its supporting layer. The supporting layer may have cracked from shrinkage stresses, load stresses, or from the reflection crack phenomenon; this supporting layer may be composed of portland cement concrete, asphaltic concrete, cement treated base, or a clay bound soil course.

The mechanism leading to the development of a reflection crack is not completely understood. However, a certain amount of knowledge and experience are available to recognize the contributions of the tensile stresses caused by the restraint at the interface when the two layers undergo thermal shrinkage and also the shear and flexural stresses that develop as a wheel rolls from one side to the other of the preexisting crack of the supporting layer.

Naturally, we consider all surface cracks as contributing distress to a pavement.

Several solutions to the reflection cracking problem have been offered; and at one time or other have been found to be successful but not often enough or economical enough to receive wide acceptance. One of the approaches used has been to resist the differential movement between the two layers with the strength of the overlay. The strength of the overlay was achieved with layer thickness or with reinforcement of wire mesh. Another approach has been to provide a yielding or "strain-relieving" layer between the old cracked layer and the new overlay, or the overlay itself was of such a pliable nature that deformations resulting from "crack" movements yielded low stresses without fracturing the surface layer.

"Asphalt-rubber" is a mixture of asphalt and fine grindings from rubber tires. It was developed and patented by C. H. McDonald in the early 1960's. In 1966, McDonald (1) reported early experiences with asphalt-rubber as a patching material for alligator type failures. Subsequent use of the asphalt-rubber as the binder for chip seal construction has shown that old pavement cracks have not appeared after at least 6 years of service. Olsen (2) has discussed the construction of asphalt-rubber chip seal coats with McDonald's binder of 25 percent rubber and 75 percent asphalt.

At the 1976 annual meeting of the Transportation Research Board, Morris and McDonald (3) presented a discussion on the use of asphalt-rubber to prevent reflection cracking. Examples of using the asphalt-rubber as a surface "stress absorbing membrane" (SAM) and also prior to overlay as a "stress absorbing membrane interlayer" (SAMI) are presented in the report. Because of the high rubber content, and the swelling and the softening of the rubber particles, the authors state that "...it is postulated that the asphalt is serving to modify the elastic properties of the rubber rather than the rubber serving to modify the characteristics of the asphalt."

The asphalt-rubber mixture has been used largely on an <u>ad hoc</u> basis and as such no laboratory tests or measurements have been made to characterize its behavior as a strain attenuating layer. The objectives of this study were to investigate established procedures or develop new ones to characterize certain physical properties of a particular asphalt-rubber blend and also to characterize the blend's capability to serve as a strain attenuating layer to preclude reflection cracking.

## ASPHALT AND RUBBER MIXTURES

The mixture of asphalt and rubber used in this study was held constant as to the amount and type of the two components. The material to be more fully identified later was a combination of a relatively soft asphalt cement and particles (#16-#25 sieve) of rubber from passenger tires; the proportion was 3 parts of asphalt to 1 part of rubber by weight basis. The mixture was specified by the Arizona Department of Transportion (ADOT) and has been labeled asphalt-rubber in opposition to rubberized asphalt. Although the asphaltic blend was not a variable in the study, a brief review of rubber in asphalt is deemed necessary to develop an understanding and significance of the jargon and factors affecting the behavior of mixture of rubber and asphalt.

The addition of rubber to asphalt would seem to be desirable since it would be expected to improve elasticity and low temperature flow properties of asphalt (4,5,6,7,8). In 1898 Caudenberg obtained a patent for a process to manufacture a rubberized asphalt (4). Of course, at that time the additive was a natural rubber. Since then various methods have been used to blend various types of natural or synthetic rubbers with asphalt. These different rubbers are described as follows:

1. Natural rubber is made from the milky sap of the rubber tree which was discovered in South America. Natural rubber is quite temperature susceptible and ages quite rapidly.
2. Vulcanization is a process for combining sulfur with natural or synthetic rubber to reduce temperature susceptibility and

improve other characteristics desirable for pneumatic tires.

3. Synthetic rubber was developed during World War II from petroleum. Although there are many types and grades of synthetic rubber, the most common type used in the manufacture of tires in a copolymer of styrene and butadiene abbreviated SBR (8).
4. Reclaimed rubber is a product from the treatment of vulcanized scrap tire rubber--"whereby a substantial "devulcanization" or regeneration of the rubber compound to its original plastic state is effected, thus permitting the product to be processed, compounded, and vulcanized." (9).
5. Rubber latex is a suspension of rubbery particles as an emulsion in water. If of natural rubber, the particles are of colloidal size and contain 20-40 percent solids; if of synthetic rubber, the solid content may be from 20-70 percent (9).

## Dispersion of Rubber in Asphalt

The literature reviewed has generally been concerned with small quantities (less than 5 percent by weight of asphalt) rubber and the size of rubber particles has not been specified. When rubber was introduced as a liquid latex, one would have to assume that rubber particles would pass through a #200 mesh sieve (0.003 inch or 75 micron). If the rubber was in a granule, crumb or powder form, then one would have to assume that the size range of these was from 0.30 inch (7.6 mm) to 0.03 inch (0.08 mm) but not the complete range for any one of the forms. There is somewhat general agreement that the rubber is not soluble in asphalt (8,9); however, a submicroscopic size particle or even an individual molecule could go into solution (4,10).

The dispersion of rubber in asphalt is usually accomplished at elevated temperatures of 280°F to 375°F (138°C to 190°C) with moderate agitation for a specified period of time. Under optimum conditions a specific particle size may increase in volume (swell) by a factor of up to 5 for natural rubber (4). The dispersion of the rubber particles to produce the desired improvements in the asphalt may be affected by the following:

1. Mixing temperature - usually detrimental if held too long above 420°F (216°C) (8)
2. Duration of mixing time. The effect is also dependent on temperature; however, the effect becomes constant after a minimum time (4)
3. Stirring shear--break down of rubber if too high (8)
4. Particle size and its distribution
5. Type and quantity of rubber (4)
6. Amount of aromatic (cyclics) component in the asphalt (8)

The review presented in the previous paragraphs was related principally to blends characterized as rubberized asphalt since the rubber content was relatively low and visual appearance of the blend was that of asphalt.

The literature on asphalt-rubber blends containing 20 percent or more of rubber is extremely limited. LaGrone et al (9) refers to a blend containing 20 percent reclaimed rubber but does not present properties of this material. Characterizations of high rubber content blends are presented by Morris and McDonald (3) Green and Tolonen (11), Frobel, Jimenez, and Cluff (12) and Kalash (13). The laboratory findings of these four reports (3,11,12,13) are related principally to a blend of 3 parts AR1000 asphalt with 1 part passenger tire rubber having a size range between the 16 to 25 mesh sizes (1.2-0.7mm) and can be summarized as follows:

1. The effect of the rubber was to increase the viscosity at temperatures above ambient and reduce the temperature susceptibility.
2. The ductility value at 77$^{o}$F (25$^{o}$C) was reduced by the addition of rubber (12,13).
3. The flow value for the Barrett Slide Test was reduced (12).
4. The tensile pullout toughness value by the Benson procedure was increased by the addition of rubber (12).

As can be seen from the above not much laboratory information is available which can be used to predict the performance of the asphalt-rubber as a strain attenuating layer (SAL).

The next sections describe tests and results obtained from measurements made on the binder by itself and also when serving in a mode simulating a strain attenuating layer.

# MATERIALS AND TESTS PROCEDURES

In this study the materials used were not to be varied; however, certain measurements had to be made to characterize these in terms of standard technology.

## Materials

### Asphalt

The low viscosity asphalt of this AR1000 grade (14) and the rubber additive were furnished by the Arizona Department of Transportation (ADOT) in sufficient quantities to eliminate a batch variable. The asphalt properties are shown in Table A1 in Appendix A; although the table does not contain information on the asphalt's composition, it has been determined that the aromatics (cyclics) component content was of a satisfactory amount and type.

### Rubber

The data appearing in Table A2 show that the particle size distribution of the rubber was such that ninety-nine percent passed the No. 16 (1.2mm) sieve, twenty percent passed the No. 30 (0.6mm) sieve, and two percent passed the No. 50 (0.3mm) sieve. The table also shows that soaking the rubber in benzene to cause the particles to swell and then drying at 140$^{o}$F (60$^{o}$C) did not change appreciably the dry size of particles.

Asphaltic Concrete

In order to minimize the effects of storage time on the physical properties of beams to be made of asphaltic concrete, a proven procedure was used. A large quantity of asphaltic concrete was obtained from a commercial plant and stored in sealed 5-gallon (19 l.) metal cans. When material was needed for making specimens, a can was placed in a 180°F (82°C) oven for 1-2 hours. After this period of time, the mixture was soft enough for sampling. Care was taken in keeping track of the weight of the mixture in the cans so that a can would not be heated in the 180°F (82°C) oven more than twice.

After obtaining the desired weight of sample, it was heated in a 250°F (121°C) oven in preparation for compaction. Compacted specimens were then stored in a room maintained at 77°F (25°C) for periods ranging in time from a minimum of three days to as much as fourteen days. Prior work (15) had indicated that this procedure was satisfactory for minimizing the effects of storage time.

Two paving mixtures were obtained from a local hot-mix plant. A mixture labelled "3/4" Tanner" was obtained for the testing sequence related to loadings of horizontal shear forces at the interface between an old pavement and a new overlay. Characteristics of this mixture are shown in Table A3 which shows test values for density, Hveem stability, and cohesiometer value for specimens compacted by two procedures. It is noted that the density of beams compacted in one layer or two layers is given for comparison with the density of 4-inch (101mm) diameter specimens.

## Test Procedures

As indicated earlier the project's goal was to develop test procedures related to reflection cracking; however, viscosity and ductility tests were performed to obtain comparative values for the straight asphalt and the asphalt-rubber.

Prior to performing any test on the asphalt-rubber it is necessary to blend the two materials. As indicated by Endres (8) and Green et al (11) the characteristics of the asphalt-rubber are dependent on the mixing procedure. The equipment, temperature, and duration used to make the blends are detailed in Appendix B.

### Viscosity Test

Viscosity tests were performed over a range of temperatures from $59^{o}$-$104^{o}$F ($15^{o}$-$40^{o}$C) using a falling coaxial cylinder viscometer. Cylinders and pistons were fabricated to satisfy that ratio of annulus width/length being less than 0.5 as recommended by Traxler and Schweyer (16).

The annulus width of the viscometer was set at 1/4 inch (6.3mm). This value was selected on the basis that the diameter of a tube should be at least five times larger than the maximum particle size of a mixture to be forced through it. If the dry rubber passes the No. 16 (0.05 in.) and swells by a factor of five according to Endres (8) or a factor of two according to Green (11) then the largest particle in the asphalt-rubber would be between 0.10 to 0.25 inch (2.5-6.3mm). Recalling that the swell factor of five was for a natural rubber, we preferred to select the swell factor of two in order to obtain a tube diameter of 0.5 inch (12.7mm) or the annulus width of 0.25 inch (6.3mm).

Photographs of the viscometers and the set-up for testing in a water bath, sample preparation, and the test procedure are described in Appendix C.

Ductility Test

Variations of the standard AASHTO ductility test were performed at temperatures of 33°, 55°, and 77°F (0.6, 12.8, and 25°C) and at extension speeds of 5, 11, and 19 centimeters per minute. Data for the asphalt and asphalt-rubber are listed in Table 6A.

Beam Tests

It is pointed out at the onset that the testing was not exactly as implied by the word "beam" since the asphaltic concrete specimen was not spanning a large clearance. (See page 89.)

The composite beam was made up of two 6 x 20 x 1/2-inch (152 x 508 x 12.7mm) aluminum plates and an asphaltic concrete specimen 5 x 12 x 2 or 4-inch (127 x 305 x 51 or 101mm). The two aluminum plates butted to within 1/32-inch (0.8mm) of each other and were joined with a tack coat and the asphaltic concrete beam. The procedure for making the asphaltic-aluminum beam is described in Appendix D.

Horizontal Shear Test. This test was used to simulate the horizontal stress that occurs at the interface of an overlay and at the crack of an old pavement that is undergoing cooling.

Appendix E contains a detailed description of the test. A review of the procedure will show that one of the aluminum plates was pulled away from the other one and that a "horizontal" shear force was carried by the tack coat to the asphaltic concrete specimen. The principal measurements made were the shear force and the amount of slip between the aluminum plate and the asphaltic concrete specimen as a continuously increasing load was applied. As noted three rates of loading were used and the tack coat was also a variable.

Vertical Shear Test. The test as described in Appendix F was developed to simulate a repeated wheel load being transmitted from one side of a crack to the other side by an overlay course.

Briefly, the test procedure involved the repeated application of a deflection to one end of an aluminum plate and establishing the number of repetitions required to crack the asphaltic beam. The main variables of the experiment were as follows:

a. amount of deflection--3 levels

b. tack coat--4 levels

c. temperature--2 levels

d. asphaltic concrete thickness--2 levels.

## RESULTS AND DISCUSSION OF TESTS

The results of the tests performed are listed in the table of Appendix A. However, pictorial presentations and additional tabulations will appear in the text of this section.

In general the discussion will be centered on indicating the differences in response to tests between straight asphalt and asphalt-rubber.

### Materials

#### Asphalt Cement and Rubber Fines

Tables A1 and A2 of Appendix A show the standard measurements made on the two materials. It is noted that the asphalt is of relatively low viscosity especially if it were to be used in a surface course in southern Arizona.

The measurements for gradation were made to characterize the particle size distribution of the rubber fines. However, of some interest are the measurements made after soaking in benzene to cause swelling of the particles and then drying for sieve analysis. The data of Table A2 indicate the swelling of the particles by soaking in benzene is similar to the swelling of a sponge when it soaks water and then shrinks when dried. This would seem to indicate that the swelling phenomenon of the rubber particles was primarily a physical one.

## Asphaltic Concrete

The data of Tables A3 and A4 are presented to show characteristics of the mixtures and to show certain comparisons between the two compactors and the two types of specimens made.

The important comparisons to show are that the procedure developed for the compaction of beams did produce densities that were comparable to those of the 4-inch (101mm) diameter ones and also that A-R tack coats did not affect the density of beams compacted on them.

## Viscosity Measurements

Viscosity measurements made on the asphalt cement and asphalt-rubber are presented in a somewhat different form that appears in the literature. Usually viscosity for asphalts is given at one specified shear rate and so the shear stress-shear rate relationship is not apparent. Table 5A presents information for describing the shear stress-shear rate relationship for asphalt cement and also asphalt-rubber at various temperatures. Also since the equations were developed statistically, the coefficient of correlation, $R^2$, is shown; note the particularly high values (.85-.99) obtained for the asphalt-rubber especially since the method for casting the test specimens was not a standard one.

Table A5 also shows the viscosities calculated at a shear rate of $5x10^{-2}$ reciprocal seconds. These viscosities were used to determine the best-fit line between viscosity and temperature using linear models of log viscosity-log$^oF$ and also log log viscosity-log$^oR$ (Rankine). The complete equations and coefficient of correlation for each are listed on Table 1. Using the log$\eta$-log$^oF$ equations from Table 1

Table 1. RELATIONSHIP BETWEEN VISCOSITY ($\eta$) AND TEMPERATURE FOR ASPHALT CEMENT AND ASPHALT-RUBBER*

| Material | Model | Equation | n | $R^2$ |
|---|---|---|---|---|
| Asphalt Cement | $\eta=IF^b$ ($F={}^oF$) | $\eta=6.767x10^{25}F^{-10.69}$ | 5 | 0.999 |
| | $Log\ \eta=IR^b$ ($R={}^oRankine$) | $Log\ \eta=3.422x10^{16}R^{-5.781}$ | 5 | 0.999 |
| Asphalt-Rubber | $\eta=IF^b$ ($F={}^oF$) | $\eta=5.768x10^{14}F^{-4.494}$ | 5 | 0.925 |
| | $Log\ \eta=IR^b$ ($R={}^oRankine$) | $Log\ \eta=7.597x10^{6}R^{-2.227}$ | 5 | 0.951 |

*Viscosity determined at a shear rate of 0.05 sec.$^{-1}$ for regression analysis.

for both materials, viscosities for three temperatures are calculated and shown below.

| | | | |
|---|---|---|---|
| Temp. $^{o}F(^{o}C)$ | 32(0) | 77(25) | 140(60) |
| Asphalt $\eta$,p. | $550x10^6$ | $460x10^3$ | 774 |
| A-R $\eta$,p. | $99x10^6$ | $1.92x10^6$ | $131x10^3$ |

The above values of viscosity show that at the higher temperature the asphalt-rubber has much higher viscosity than the asphalt but at the lower temperature the opposite is true; and of course, this lower temperature susceptibility of the asphalt-rubber is very desirable. (The calculated viscosity of the asphalt at $140^{o}F$ ($60^{o}C$) compares favorably with the measured value of 744 p. shown in Table A1).

## Ductility Value Measurements

The standard AASHTO ductility test for asphalts was modified with reference to speed of elongation and temperature conditions. These variations were made to obtain comparative measures for the deformability of the asphalt-rubber.

Table 6A of Appendix A shows that the AR-1000 asphalt stretched the full distance of the device for all three speeds with the two higher temperatures; however, the ductility value was zero for all three speeds with the test temperature of $33^{o}F$ ($0.5^{o}C$).

The asphalt-rubber specimens did not show much response to the speeds or temperatures used in that the total range of values was from 16 to 29; even for the lowest temperature the values were from 16 to 22.

It was noted that there was not much dimensional reduction in the transverse direction while the test was underway and then some of the reduction was recovered after fracture.

Again, we note the better low temperature response of the asphalt-rubber.

The reduced value of ductility for the asphalt rubber at 77°F (25°C) is contrary to the findings of others (7,8) when small amounts of latex are used to make rubberized asphalt. The reduced elongation of the asphalt-rubber is attributed to the consideration that the rubber particles are behaving as elastic aggregate in the blend. Under this condition, it is anticipated that the asphalt-rubber blend may have a reduction in cohesion and adhesion values as compared to those of the straight asphalt.

## Horizontal Shear Test

As mentioned earlier, the variables in this part of the experiments were (a) rate of loading, (b) asphalt beam thickness, and (c) amount of A-R tack coat. The zero level of tack coat was actually a tack of RC-250 applied at a rate of 0.05 gallon per square yard.

The question may arise as to whether or not the aluminum plate can be said to represent an actual pavement surface. Also as mentioned earlier, this test examines the capability of the tack coat to transfer the shear force from the aluminum plate to the asphalt beam. Repeated examination of the failed specimens showed that for the RC-250 tack coat fracture occurred at the beam interface and for the A-R tack coats fracture occurred within the tack-coat. Since at no time did fracture occur at the aluminum plate interface, then the objectives of the test were reached.

The data for the horizontal shear test appear in Tables 7A and 8A of Appendix A. The numerical values shown in the table were obtained from plots of load and slip versus time as shown in Figures 1 and 2. From Figure 1 for the R-C tack coat it is evident that fracture occurs at the maximum load applied. However, examination of Figure 2 shows that an ultimate amount of load is maintained for awhile as the rate of slip increases until fracture of the A-R tack coat results from shear. This last behavior was not noticed when the first A-R beams with 0.6 g.s.y were tested and as a result the loading was stopped as soon as it started to decrease as was done with the beams tacked with RC-250. It will be noted that the measurements for slip at rupture and load at slip rupture are not available for the 0.6 g.s.y. A-R beams.

The general indications of the data obtained for this test are that the A-R tack coat is stronger than the RC-250 at low deformation rates but weaker at high deformation rate; however, the extensibility of the A-R tack coat is much greater than that of the RC-250 and its value increases with an increase of deformation rate.

The next three figures show comparisons between A-R and RC-250 data. Figure 3 shows the effects of extension rate and amount and kind of tack coat on the maximum load obtained in the horizontal shear test. It is seen that the A-R tack coats are less susceptible to rate of loading and that the strength of the A-R tack coat decreases as the thickness (application rate) increases.

Figure 4 shows the effects of extension rate on the amount of slip occurring at maximum load; however, at maximum load, failure or rupture of the A-R tack coat has not occurred. Note that the effects of type and amount of tack coat are opposite to those shown in Figure 3, that is, for RC-250 the amount of slip decreases as the extension rate increases and the amount of slip increases as the amount of A-R increases.

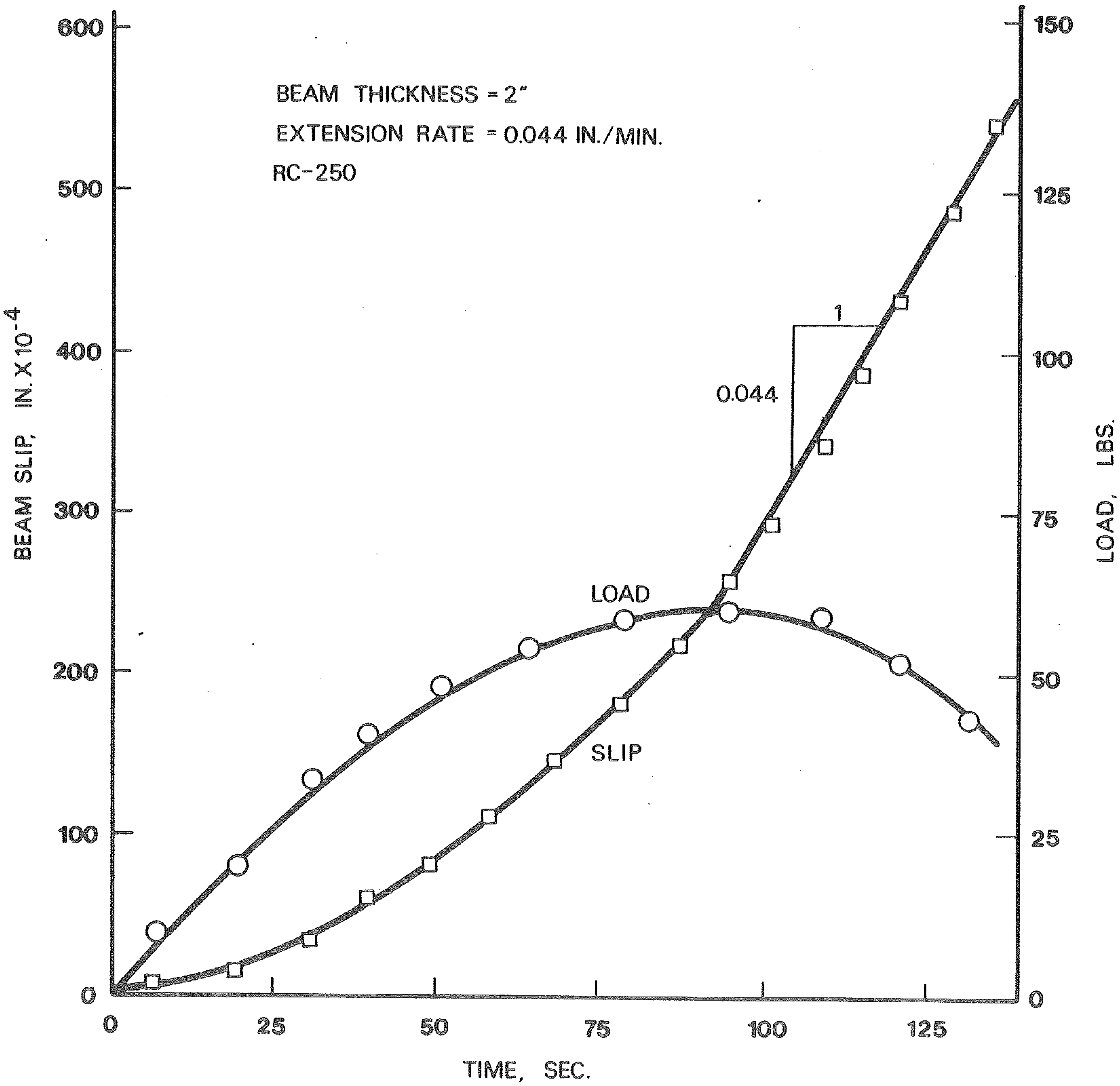


Figure 1. Typical Plot of Load and Slip vs. Time for RC-250 Tack Coat

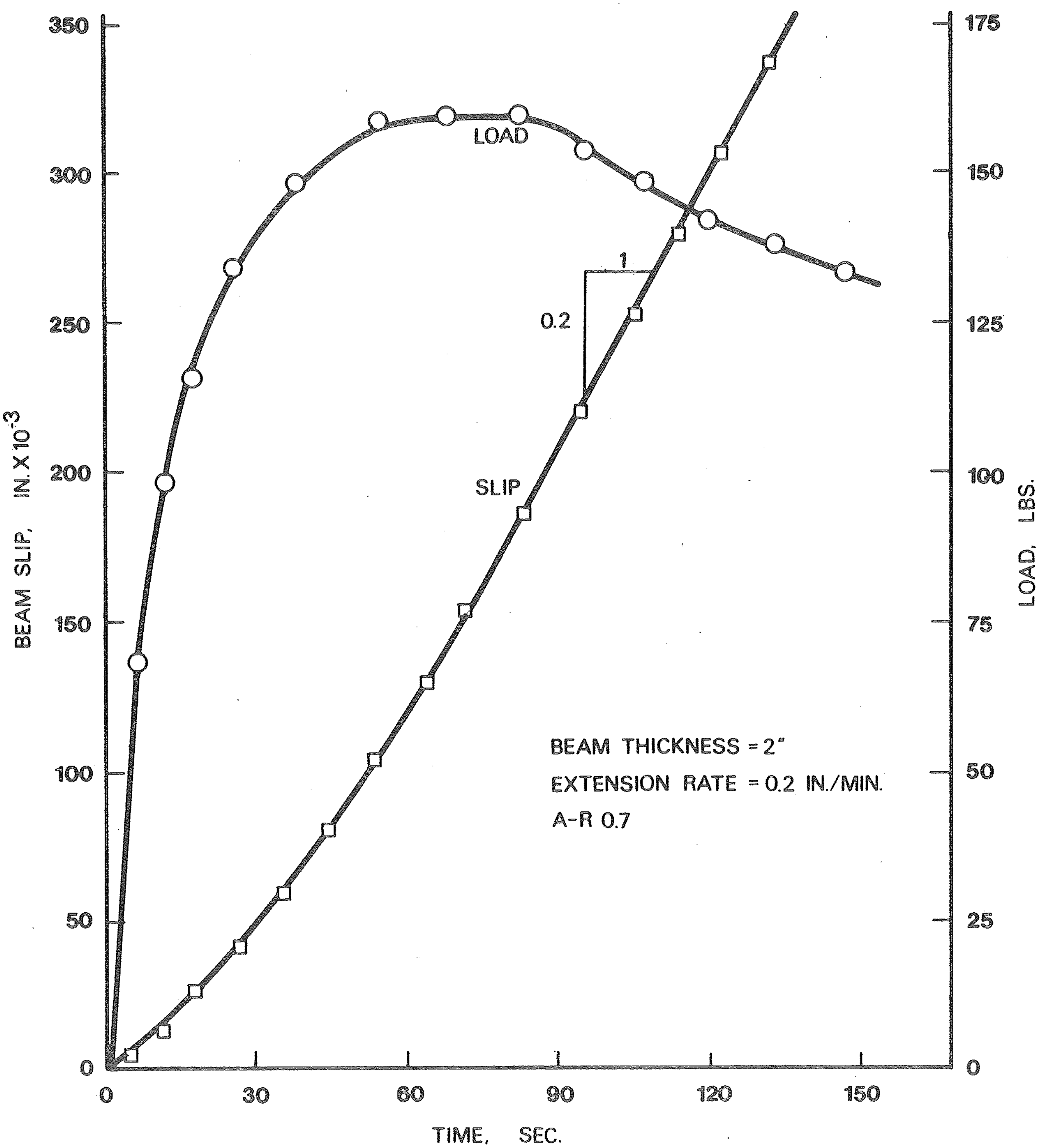


Figure 2. Typical Plot of Load and Slip vs. Time for A-R Tack Coat

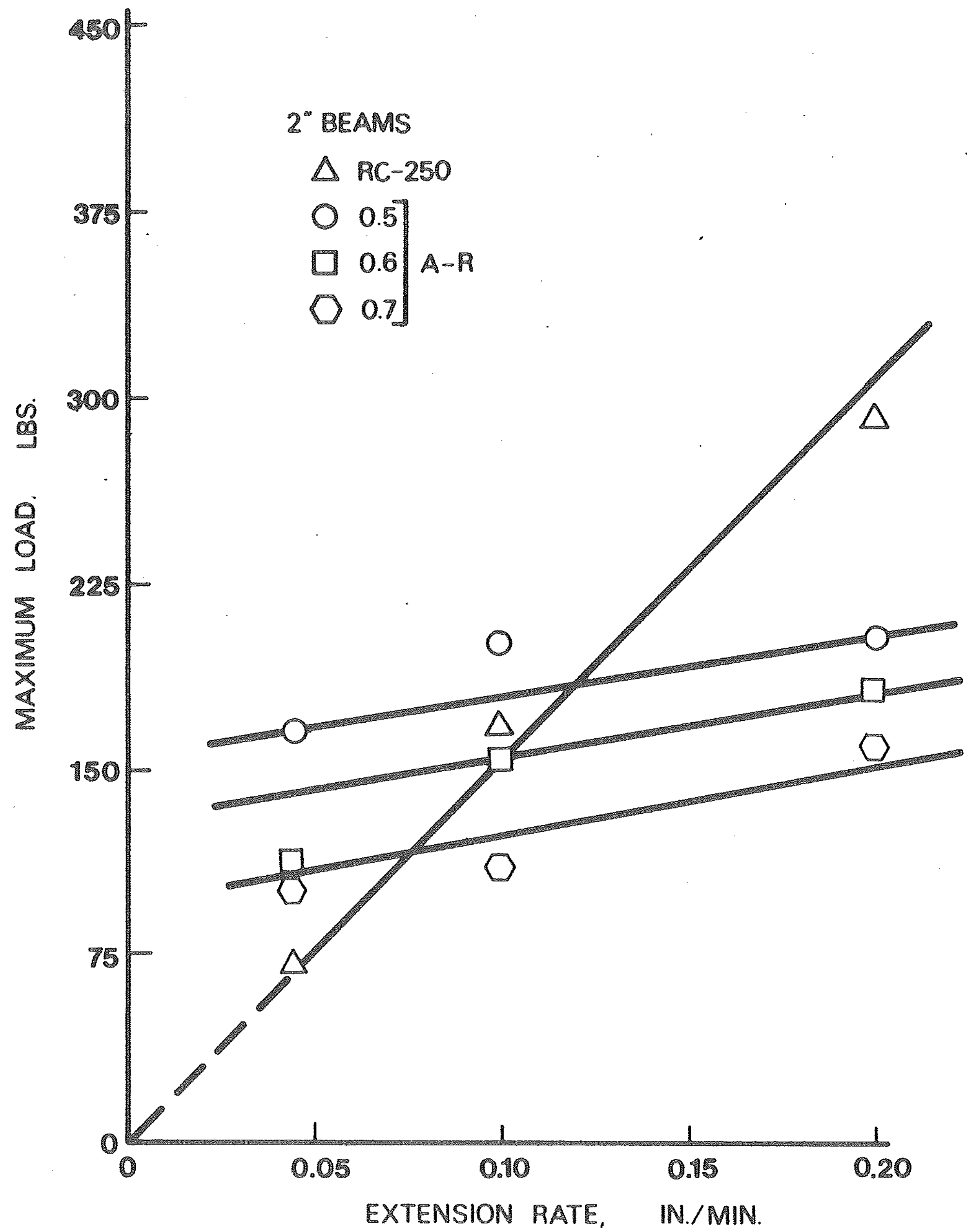


Figure 3. Relationships between Maximum Load and Extension Rate in the Horizontal Shear Test for RC-250 and A-R Tack Coats

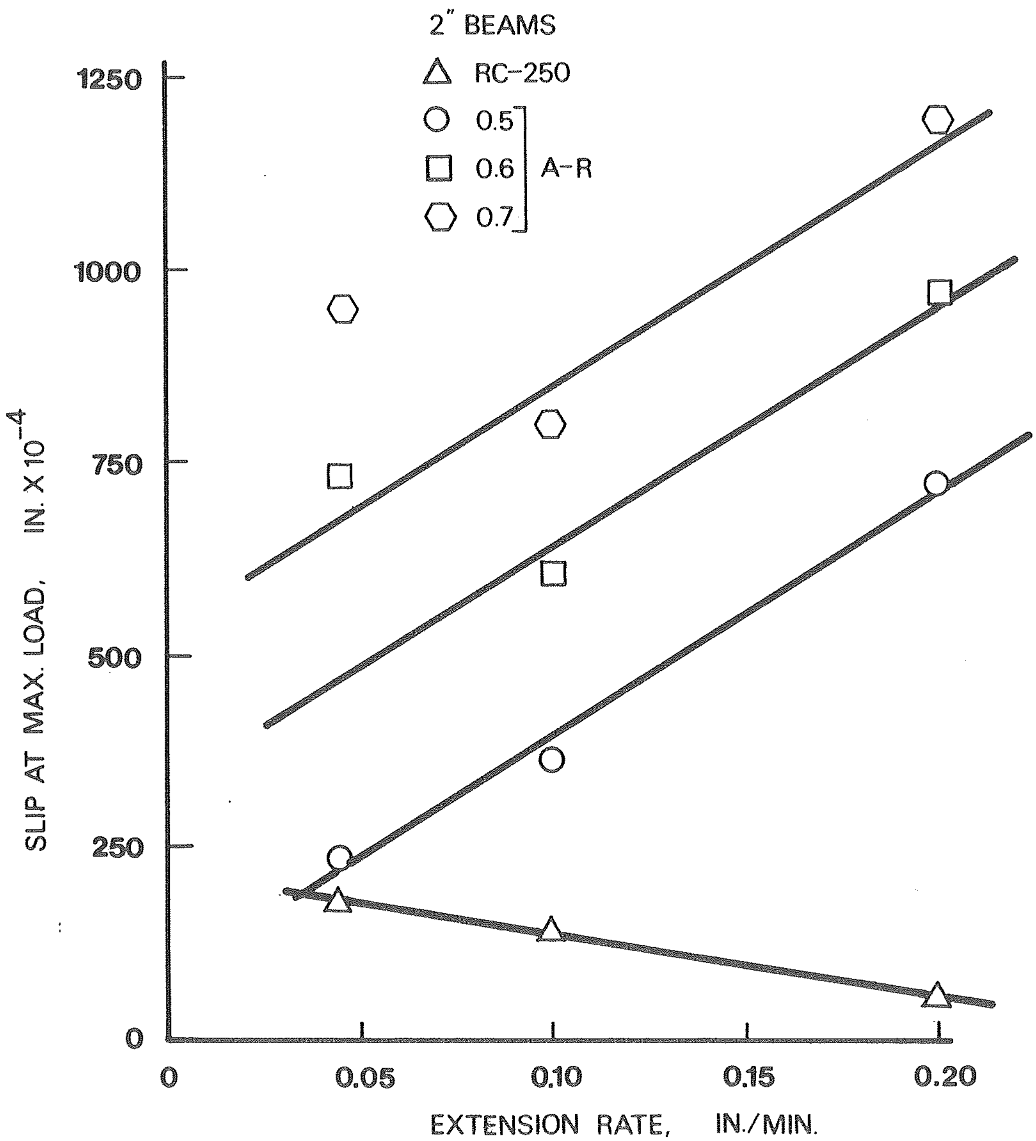


Figure 4. Relationship between Slip at Maximum Load and Extension Rate in the Horizontal Shear Test for RC-250 and A-R Tack Coats

A composite of Figures 3 and 4 to show the significant and great differences in response to the horizontal shear test between the RC-250 and A-R tack coats is presented in Figure 5. The curves show the reason for the A-R tack coat to serve as a strain attenuating layer in that large strains (slip) result in relatively small loads being transmitted by the SAL in comparison to the standard use of RC-250 as a tack coat.

The above figures and discussion have been related to beams 2 inches (51mm) in thickness. The comparison between RC-250 and A-R tack coats on 4-inch (101mm) beams for maximum load and slip at maximum load are similar to those for the 2-inch (51mm) beams. However, the effects of amount of A-R were not as directional as for the 2-inch (51mm) beams. Examination of Table 8A and Figure 6 shows that the maximum load for the 4-inch beams was greater than for the 2-inch beams at 0.5 and 0.7 g.s.y A-R for all of the extension rates. However, the value of slip at the maximum load was greater for all of the 2-inch beams. It then becomes apparent that the performance of the A-R as a strain attenuating layer with regards to horizontal forces is maximized at the <u>lower</u> thickness of overlay and at the greater application of A-R. It is also noted that the extensibility of the 4-inch beam with 0.7 g.s.y. A-R is greater than that for the 2-inch beam with 0.5 g.s.y. A-R. The data are not extensive enough to optimize beam thickness with the application rate of the A-R tack coat but the data do imply that as the overlay thickness is increased then the A-R application rate should also be increased.

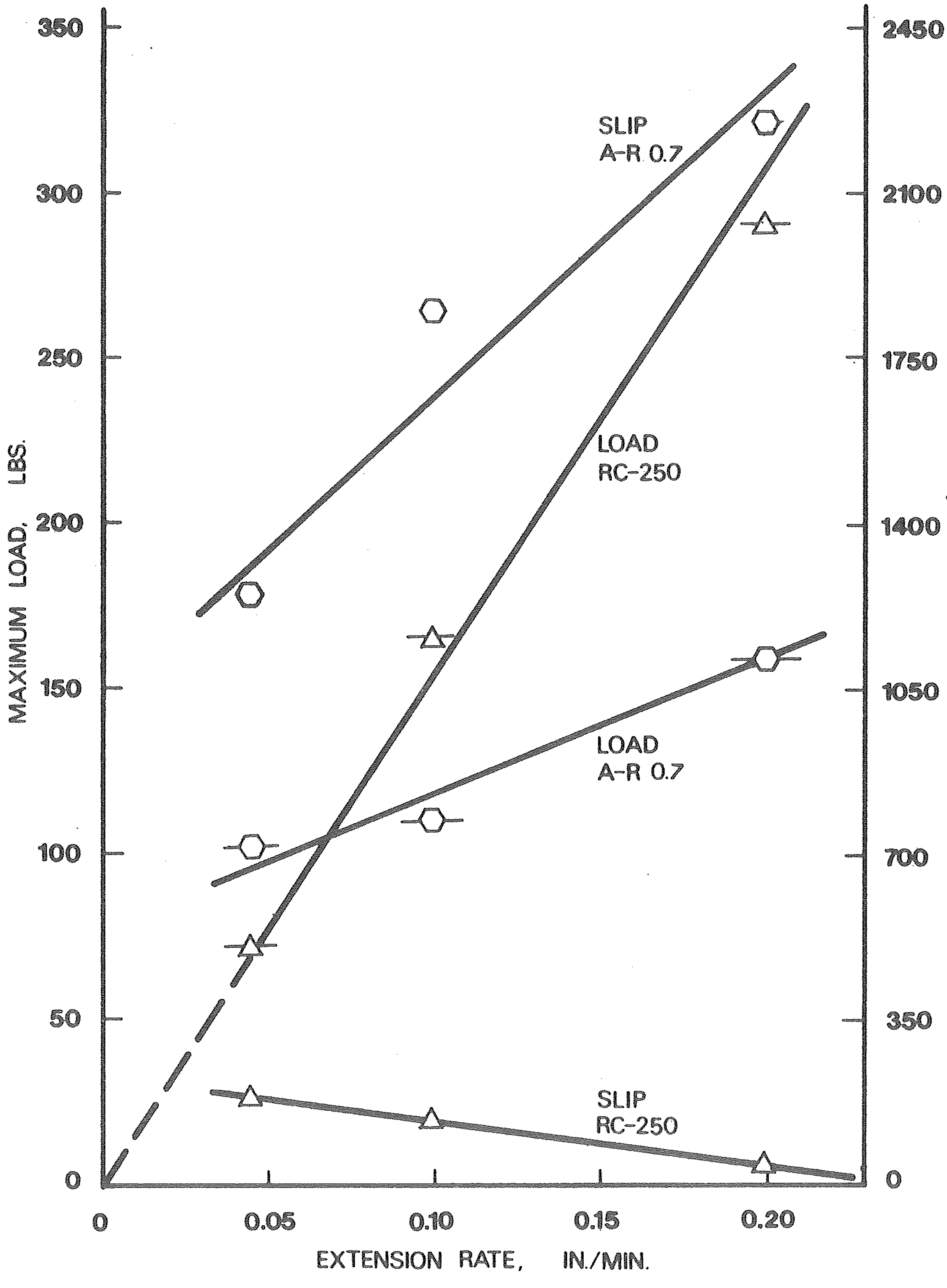


Figure 5. Comparison of Load and Slip Responses for RC-250 and A-R Tack Coats in the Horizontal Shear Test

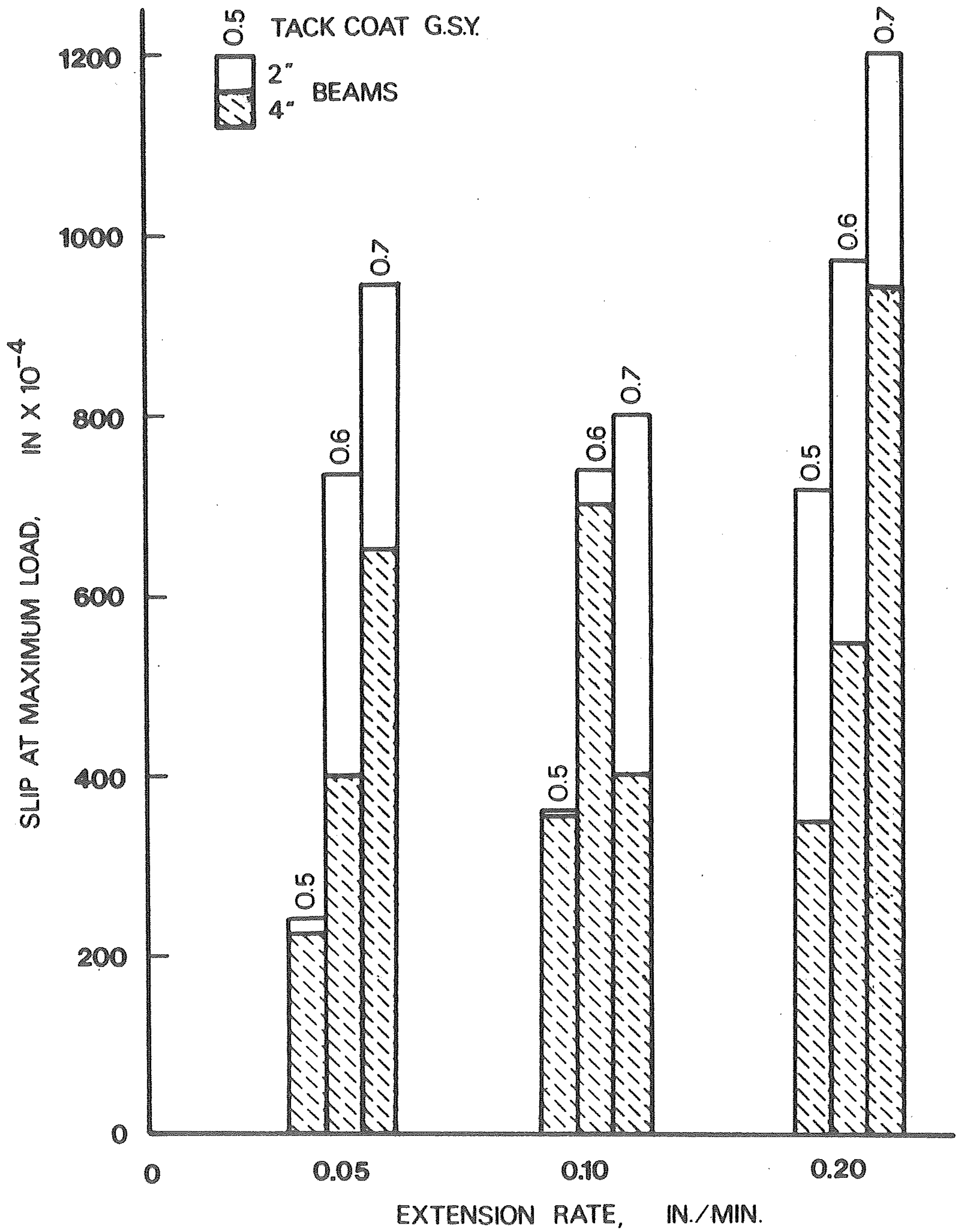


Figure 6. Effects of Beam Thickness and Amount of A-R on Slip in the Horizontal Shear Test

Vertical Shear Test

The vertical shear test was devised to simulate the condition resulting when a wheel load is transferred from one side of a crack to the other by means of an overlay. Field measurements for studies of reflection cracking have been principally the deflections near a crack under load (17,18). For this reason, the test was designed for inducing repeated deflections at the joint of the laboratory prototype of a pavement. The principal variables to be related to number of deflection repetitions causing failure of the beam were (a) amount of tack coat, (b) thickness of beam, and (c) test temperature. The data obtained from the testing program appear in Table 9A and 10A of Appendix A.

As described in the procedure, the response desired for a repeated deflection was the number of repetitions to cause a crack in the asphaltic concrete beam. Figure 7 shows various plots of deflection vs. repetitions to failure. It is noted that the plots are linear in the log-log coordinate system and that the 4-inch (101mm) thick beams have a longer "fatigue" life than the 2-inch (51mm) ones. It must be mentioned now that a greater force was required on the thicker beam to cause the same deflection as on the thinner one.

The linearity of all plotted data suggested the general model for relating deflection to repetitions in the following form:

$$\delta = I_o N^{-b}$$

where $\delta$ is the repeated deflection

$I_o$ is a constant,

$N$ is the number of repetitions to cause failure

$b$ is a constant.

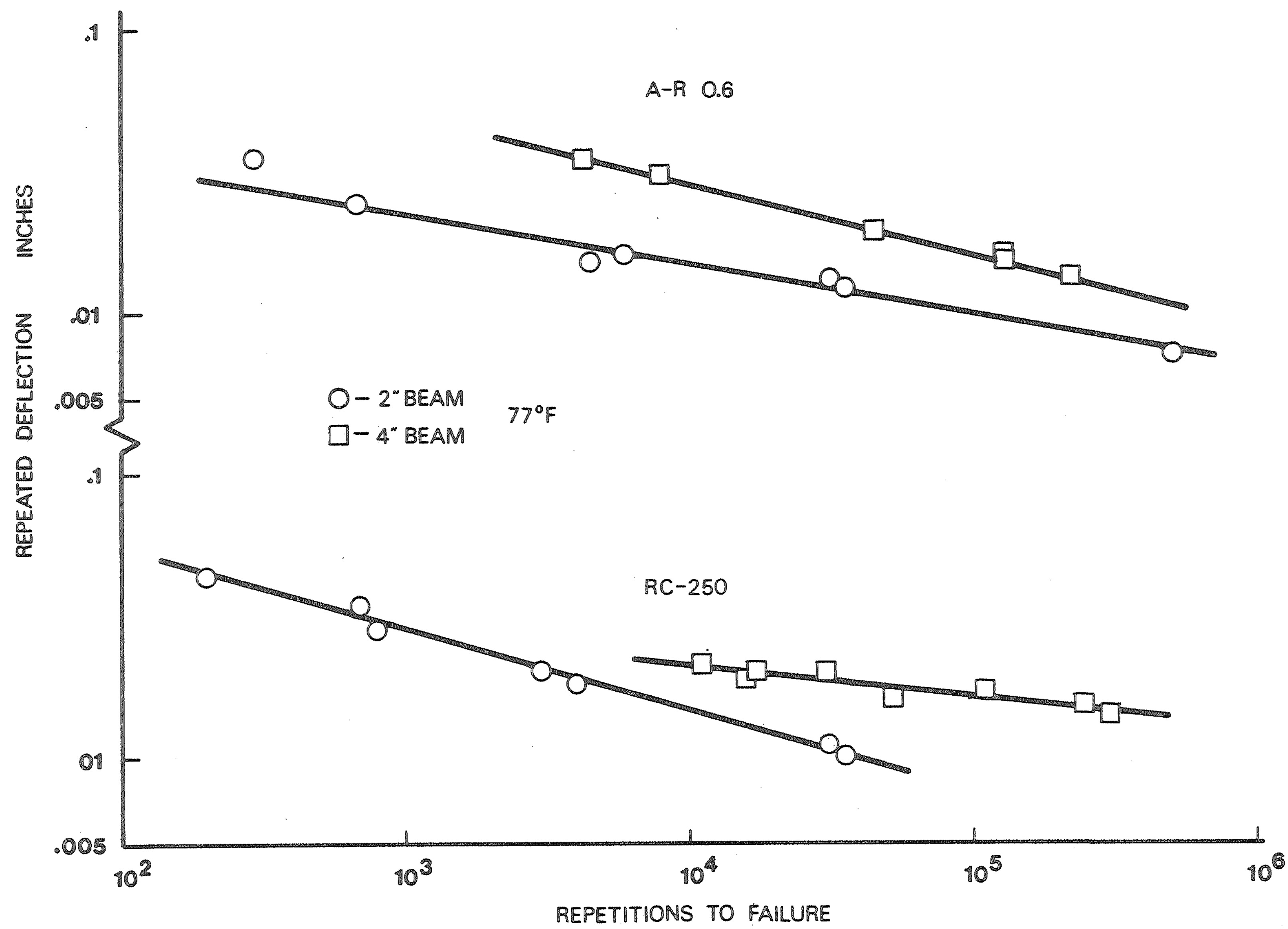


Figure 7. Relationship between Repeated Deflection and Number of Repetitions to Cause Failure in the Vertical Shear Test

Evaluation of the constant $I_o$ and b by means of a least-squares-fit yielded the values shown in Table 2. It is noted that the values for the coefficient of correlation $R^2$ are relatively high which indicates the acceptance of the model. As with any other model determined in the method mentioned, one must not attempt to use values extrapolated past the measured data. This is especially true for these data since there is a suspicion that an endurance limit may exist at deflections approaching 0.005 inch (0.13mm). Although only two sets of measurements (one in Table 9A and the other in Table 10A) are presented, during the initial testing with the device it was noticed that extremely long periods of time were required to fail a beam under small deflections.

Examination of the values for b in Table 2 for the 2-inch beams tests at 77°F (25°C) shows that there is not much difference among them. This suggests that there was no significant difference in the response of the beams with the different tack coats.

The effect of reduced test temperature on response of the beams can be estimated from the data for the RC-250 and A-R 0.6 specimens. From Table 2 it is noted that the slope of the log $\delta$-log N curve, as described by the value of b, decreases from 0.252 to 0.206 a difference of 0.048 for the A-R 0.6 beams while the difference in slope is 0.172 for the RC-250 beams. This reduction in susceptibility to temperature of the A-R beams goes along with the findings of the ductility test.

The effects of beam thickness on the response to the vertical shear test could not be explained in terms of the tack coat interaction. As a consequence, an elastic analysis of the testing system was performed. Professor DaDeppo of the Civil Engineering Department developed

TABLE 2. RELATIONSHIP BETWEEN REPEATED DEFLECTION, $\delta$, AND NUMBER OF REPETITIONS TO CAUSE FAILURE, N, IN THE VERTICAL SHEAR TEST.

$$\delta = I_o N^{-b}$$

| Tack Coat | Temp. | $I_o$ | b | n | $R^2$ |
|---|---|---|---|---|---|
| | | 2" Beam | | | |
| RC-250 | | 0.205 | 0.287 | 7 | 0.980 |
| A-R 0.5 | 77°F | 0.151 | 0.243 | 6 | 0.998 |
| A-R 0.6 | (25°C) | 0.180 | 0.252 | 7 | 0.991 |
| A-R 0.7 | | 0.261 | 0.300 | 7 | 0.973 |
| RC-250 | 38°F | 0.060 | 0.115 | 7 | 0.943 |
| A-R 0.6 | (3.3°C) | 0.134 | 0.206 | 8 | 0.987 |
| | | 4" Beam | | | |
| RC-250 | 77°F | 0.060 | 0.115 | 8 | 0.900 |
| A-R 0.6 | (25°C) | 0.264 | 0.243 | 6 | 0.990 |

expressions for stresses within the composite beam assuming linear elasticity. This development is described in Appendix G.

A further effort for the evaluation of stresses in the composite system was to write a computer program for the calculation of deflections, flexural stresses, axial stresses, and shear stresses at different points in all three materials of the beam. It was not the intent to delve too deeply into the effects of material properties or dimensions on the stresses of the system since the analysis was based on linear elastic theory. However, a fixed set of material properties was used to see how thickness of the asphalt beam and thickness of the tack coat affected certain stresses in the system and then replace the corresponding stresses with deflection in the deflection-repetition fatigue relationship.

The first step to accomplish the above goal was to establish load-deflection relationships for various of the composite beams mounted on the vertical shear test device. The beams were loaded with a cable-bucket-falling shots system at a rate of 1200 grams per minute and deflection readings on the beams were taken at specified time intervals. Figure 8 shows the plotted load-deflection data for the beams loaded as described above. The curves of the plot give an indication of the linearity between load and deflection being affected by beam thickness or test temperature. The procedure used was not capable of responding to differences in the tack coat.

The deflection and beam component sizes were used to calculate the corresponding load with the results of the elastic analysis of the system for assumed values of moduli and Poisson's ratio. A comparison between the measured and calculated loads is shown in the curves of

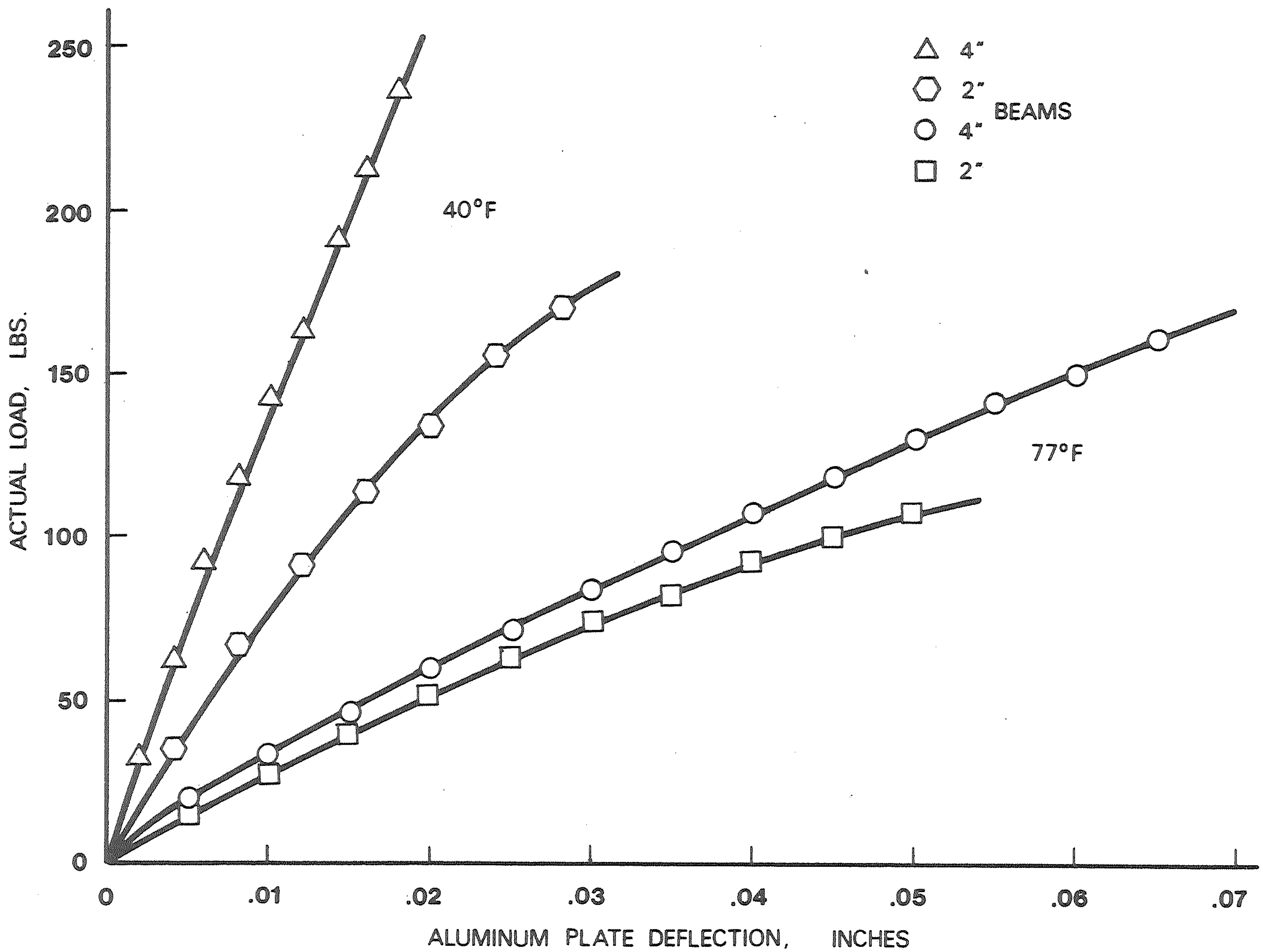


Figure 8. Relationship between Measured Force and Aluminum Plate Deflection for the Vertical Shear Test

Figure 9. The reader is reminded that the calculated load for a deflection is not affected by temperature as the measured load was; also the measured load was not affected by the amount of tack coat but the calculated load was. Our concern was not so much with the above considerations but more so with the linearity of the plotted data of Figure 9, for if the data deviated excessively from a straight line then the calculated stress could not be substituted for deflection in the deflection-repetition fatigue relationship. The plots shown in Figure 9 were assumed to be sufficiently linear and so certain stresses were calculated for a point above the crack (joint) and in the asphalt beam as well as in the tack coat assuming that the integrity of the beam was maintained up to the point of fracture. This assumption appears to be valid since the deflection across the crack was relatively constant up to the point of fracture.

The values of stresses calculated to replace deflection in the fatigue equation are shown in Table 3. Using the equations shown in Table 2, the number of repetitions to cause failure were calculated for deflections of 0.010 and 0.035 inch (0.25 and 0.89 mm). The measured loads to cause the above deflections were used to calculate tensile and shearing stresses above the joint in the tack coat and also the asphaltic beam. The following indicates the thickness of the corresponding application of tack coat:

A-R 0.7 g.s.y equaled 0.125 in. (3.2 mm)

A-R 0.6 g.s.y equaled 0.107 in. (2.7 mm)

A-R 0.5 g.s.y equaled 0.089 in. (2.3 mm)

RC-250 0.05 g.s.y assumed to equal A-R at 0.004 in. (0.10 mm).

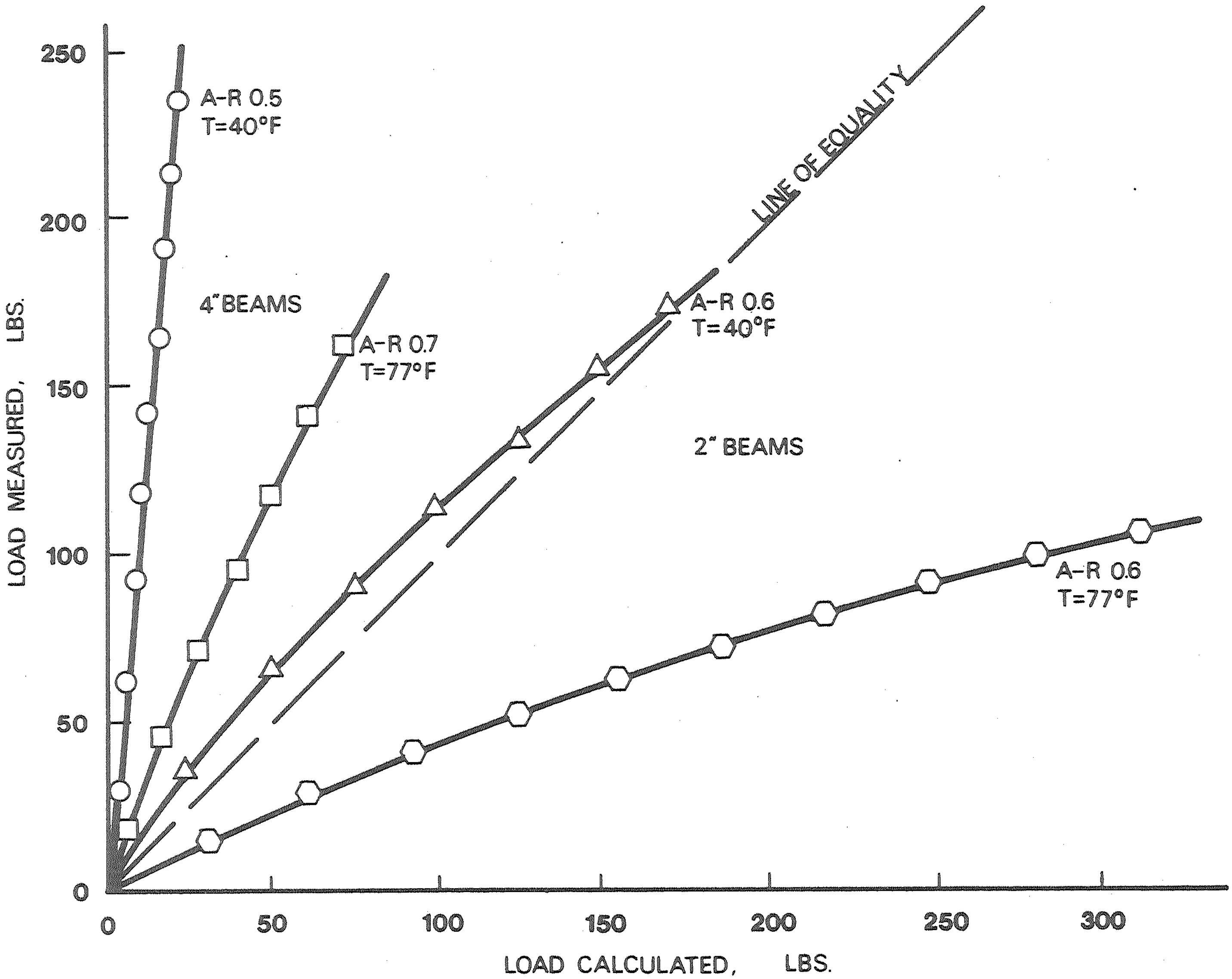


Figure 9. Relationship between the Measured Force vs. the Calculated Force at Equal Deflections for the Vertical Shear Test

TABLE 3. Calculated STRESSES AND REPETITIONS TO FAILURE FOR BEAMS TESTED UNDER VERTICAL SHEAR TEST

| Tack Coat | Beam Thickness, in. | Repeated Defl., in. | $N_f$ $10^3$ | P lb | $\sigma T_1$ [1] psi | $\sigma T_2$ [2] psi | $\tau_1$ [3] psi | $\tau_2$ [4] psi |
|---|---|---|---|---|---|---|---|---|
| | | Temperature of 77°F (25°C) | | | | | | |
| RC-250 | 2 | 0.010 | 37.1 | 28.2 | 34.9 | 33.7 | 8.1 | 19.4 |
| | | 0.035 | 0.471 | 82.0 | 101. | 98.0 | 23.6 | 56.3 |
| | 4 | 0.010 | 5590 | 33.4 | 11.4 | 19.7 | 1.9 | 8.8 |
| | | 0.035 | 0.104 | 94.8 | 32.3 | 55.7 | 5.3 | 25.0 |
| A-R 0.5 | 2 | 0.010 | 0.711 | 28.2 | 30.7 | 10.2 | 2.6 | 2.1 |
| | | 0.035 | 0.410 | 82.0 | 89.3 | 29.7 | 7.7 | 6.2 |
| A-R 0.6 | 2 | 0.010 | 95.8 | 28.2 | 30.5 | 9.6 | 2.6 | 1.8 |
| | | 0.035 | 0.664 | 82.0 | 88.6 | 27.9 | 7.4 | 5.2 |
| | 4 | 0.010 | 708 | 33.4 | 10.5 | 7.8 | 1.4 | 0.6 |
| | | 0.035 | 4.09 | 94.8 | 29.8 | 22.3 | 4.0 | 1.7 |
| A-R 0.7 | 2 | 0.010 | 52.7 | 28.2 | 30.2 | 9.1 | 2.5 | 1.6 |
| | | 0.035 | 0.810 | 82.0 | 87.8 | 26.5 | 7.2 | 4.6 |
| | | Temperature of 40°F (4°C) | | | | | | |
| RC-250 | 2 | 0.010 | 6066 | 75 | 92.8 | 89.6 | 21.6 | 51.5 |
| | | 0.035 | 0.109 | 193 | 23.9 | 231 | 55.6 | 133 |
| A-R 0.6 | 2 | 0.010 | 296 | 75 | 81.0 | 25.5 | 6.8 | 4.8 |
| | | 0.035 | 0.676 | 193 | 208 | 65.6 | 17.5 | 12.3 |

1. Total tensile stress in the asphaltic beam at the joint.
2. Tensile stress in the tack coat at the joint
3. Horizontal shear stress in the asphaltic beam at the joint.
4. Horizontal shear stress in the tack coat at the joint.

Note: The stresses shown above were calculated assuming the following elastic properties for the materials in the beams.

| | | |
|---|---|---|
| Asphaltic Concrete | $E = 2 \times 10^5$ psi | and $\nu = 0.35$ |
| Tack Coat | $E = 2 \times 10^3$ psi | and $\nu = 0.45$ |
| Aluminum | $E = 1 \times 10^{11}$ psi | and $\nu = 0.33$ |

A plot of log tensile stress-log repetition is shown for asphaltic beams as well as for the corresponding tack coats in Figure 10. The figure shows a separation by beam size and by tack coat.

For tensile stresses in the beams it is noted that tack coat had no effect on the fatigue relationship for the 2-inch (51 mm) beams as has been noted earlier based on deflections. For the 4-inch (101 mm) beams relationship is not definitive.

The points for the 4-inch beams do not fall on the 2-inch beam line which is as it should be since the test specimens were not linear elastic materials and thus a transverse plane in the asphaltic beam before bending will not be a plane after bending.

In the elastic analysis of the composite beam the tack coat was assumed to act as a membrane, that is, it did not have bending stresses but axial ones. As a consequence the data points for tension in the tack coats seem to be greatly affected by type of tack coat and not largely affected by beam thickness.

A plot of points similar to that of Figure 10 is shown in Figure 11 for the maximum shear stress in the beams. The data points for shear stress in the tack coat are not shown since no significant relationship was obvious for this comparison. Figure 11 does show that points representing the 2 and 4-inch beams with all tack coats of A-R do have a locus about a straight line.

In general it appears that the fatigue life developed experimentally between deflection and number of repetitions to failure could be more generally represented with the calculated shear stress in the asphaltic beam and to a slightly lesser degree with the calculated tensile stress

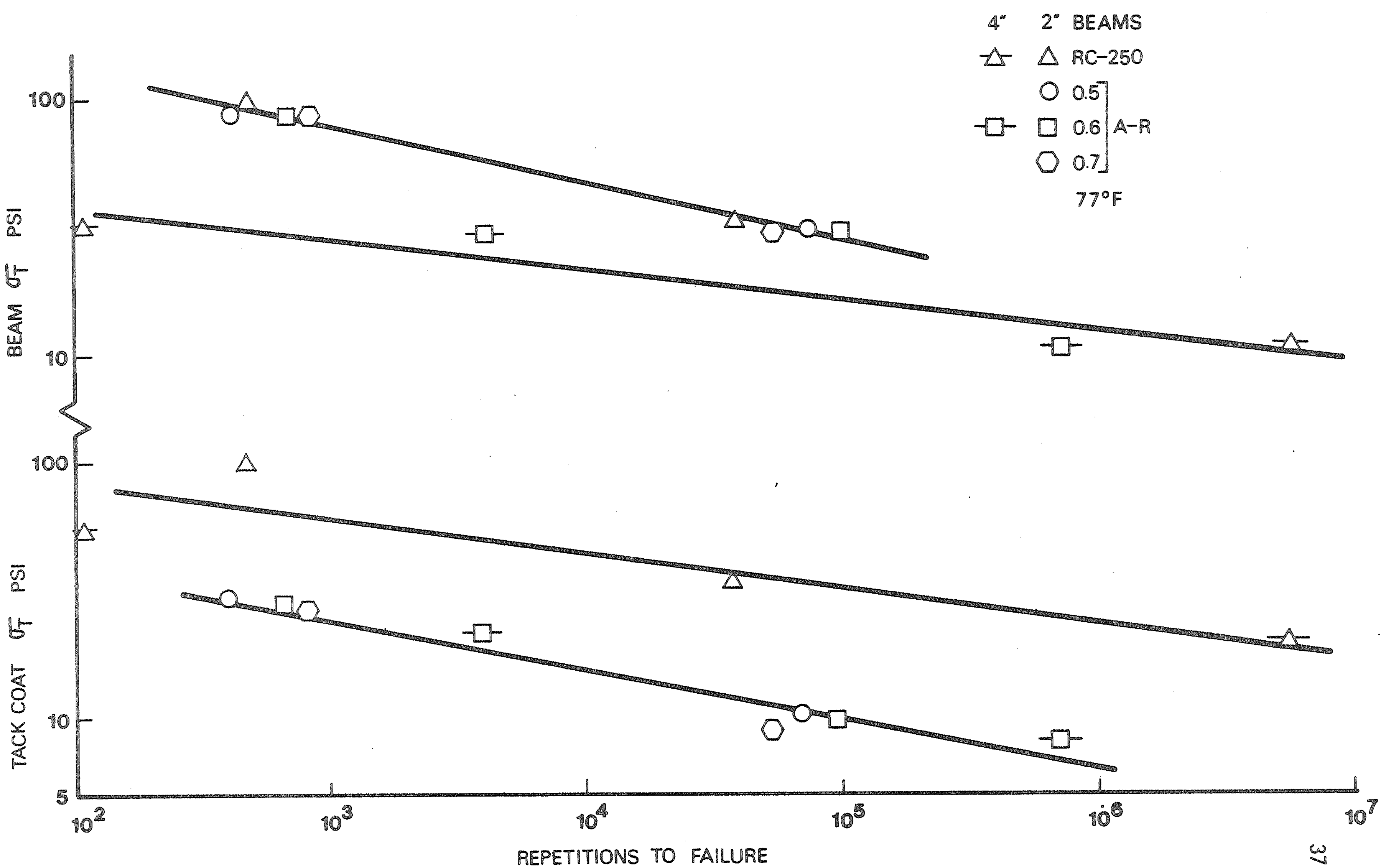


Figure 10. Relationship between Repeated Tensile Stress and Number of Repetitions to Cause Failure in the Vertical Shear Test

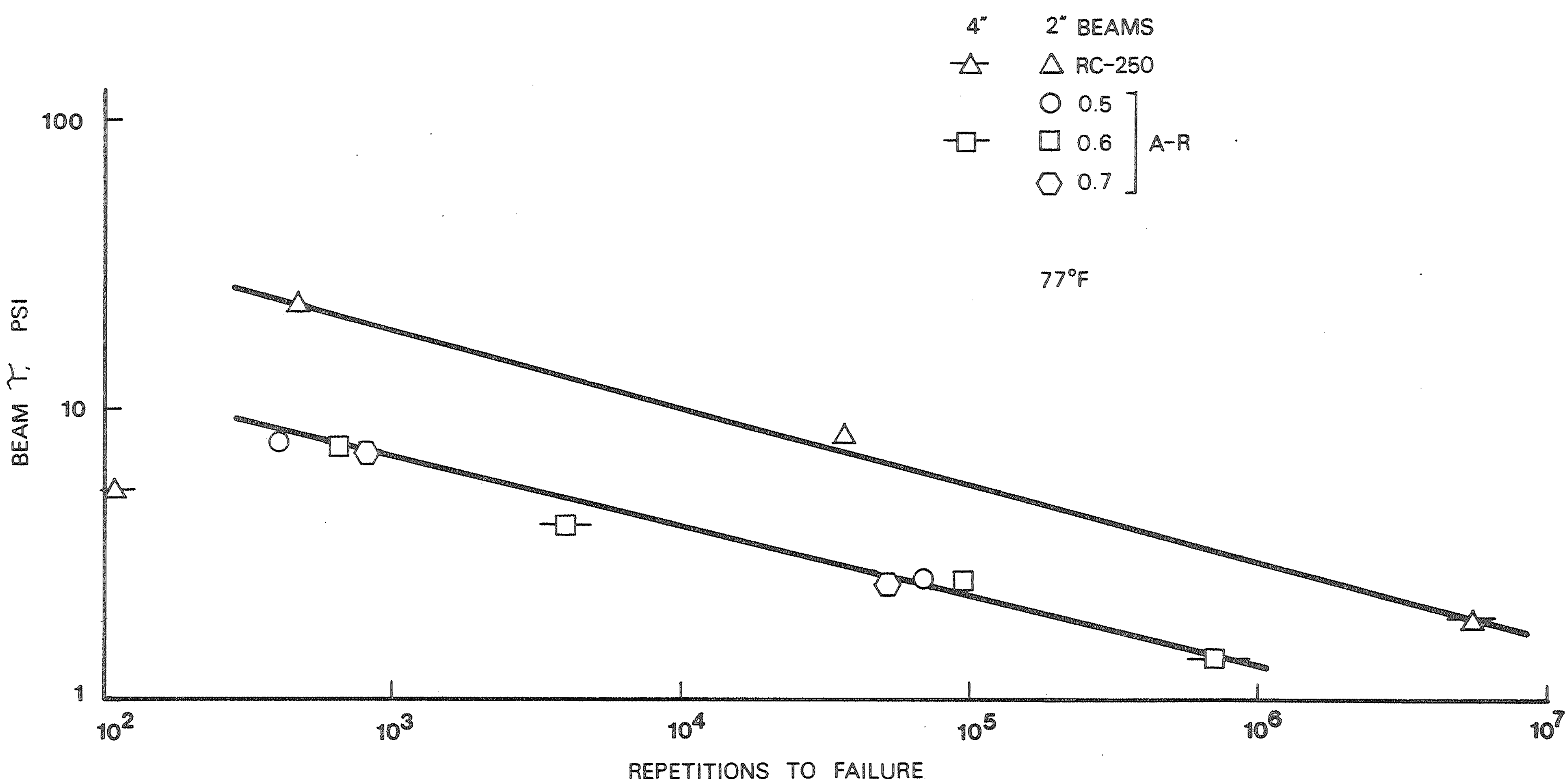


Figure 11. Relationship between Repeated Shear Stress and Number of Repetitions to Cause Failure in the Vertical Shear Test

in the tack coat. Of course, the calculated data are somewhat limited especially since only one set of elastic values for modulus of elasticity and Poisson's ratio was used for each material of the composite beam.

## CONCLUSIONS

The work performed in this study was aimed at determining or developing test methods for characterizing asphalt-rubber for its performance as a strain attenuating material and pavement layer. The literature review and tests performed have been discussed with reference to the material, A-R, and its performance as a layer in a composite beam tested under simulated service conditions that result in reflection cracking.

Within the limits of the materials and scope of the study, the findings and conclusions are summarized as follows:

1. The swelling of the rubber particles by benzene (an aromatic compound) was primarily a physical effect.
2. The mixing and storage procedure used for A-R resulted in a constant material for storage time varying from 3 days to 3 weeks.
3. The falling coaxial cylinder viscometer built to make viscosity measurements of the A-R and base asphalt produced acceptable repeatability of measurements.
4. The viscosity of the A-R was about 200 times greater than the base asphalt at $140^{o}F$ ($60^{o}C$) but about 6 times smaller than the asphalt at $32^{o}F$ ($0^{o}C$).
5. The variations of the ductility test performed indicated that the A-R's values were not significantly affected by the temperature changes from $77-33^{o}F$ ($25-0.5^{o}C$).

6. The literature survey and the ductility test results suggest that the rubber fines act as elastic aggregate in the A-R blend. On this basis it would be anticipated that the A-R may have lower values of cohesion and adhesion than the straight asphalt.
7. The test results from the horizontal shear test (simulating thermal stresses) indicate that the A-R will serve quite effectively as a strain attenuating layer and that heavier applications of A-R are necessary as the thickness of the overlay increases. Data were not obtained to establish a safe maximum thickness of A-R for use as a SAL.
8. The results from the vertical shear test (simulating repeated wheel load shear) suggest that the principal benefits of the A-R serving as a SAL came from maintaining its pliability at lower temperatures. The data for the 77$^{0}$F (25$^{0}$C) did not show significantly difference in performance for the tack coats (SAL) of RC-250 and the A-R.
9. The calculation for stresses in the composite beam based on linear elastic theory indicated that tensile stress in the SAL and also the shearing stress in the asphaltic beam (overlay) could represent deflection in the repeated deflection versus number of repetitions to cause failure ( $\delta$-N) fatigue relationship found with the vertical shear test.
10. It is believed that the equipment developed for the two test procedures for evaluation of SAL proved to yield repeatable results. However, an expanded laboratory testing program and field verification is necessary.

11. As with the new testing procedures developed, the mathematical analysis for stresses in the composite beam should be expanded for numerically detailing the value of stresses throughout the composite beam.

## Recommendation

The results of this research have yielded positive and directional expressions for the A-R to serve as an effective strain attenuating layer. It is recommended that a designed field experiment be conducted in which the principal variables be (a) amount of A-R, (b) the thickness of overlay, and (c) stiffness of the pavement system.

## Implementation Statement

This study is concerned with laboratory testing of an asphalt and rubber (A-R) mixture with special emphasis towards its use to minimize reflective cracking. Two special tests were developed to compare A-R and RC-250 as tack coats and acting as strain attenuating layers (horizontal shear test); a repeating beam deflection test (vertical shear test).

Both test procedures will undergo further testing and evaluation.

## ACKNOWLEDGEMENT

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Finally, we sincerely appreciate the support given by the sponsorship of this work by ADOT and FHWA for we believe that the work to develop efficient SAL's will be fully justified economically.

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